The Journal of Engineering Geology, Vol.8, No.3, December, 1998, pp.235-246

아스팔드 표면에 사용되는 자갈골재 평가 과정 개발에 대한 연구

A Study on the Development of a Procedure to Identify Gravel Aggregates for Bituminous Surfaces

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요약/ABSTRACT

Adquate friction resistance is needed to prevent pavement slipperiness and to allow vehicles to stop in a reasonable distance. Performance of the aggregates is reduced over time by wear and polishing as a consequence of vehicular traffic. In this research, the objective was to develop a laboratory method to test Indiana gravel aggregates to predict field performance, and determine causes for the range of values amang gravel aggregates. The assessment of gravel sources was primarily on the basis of individual rock types and those proportions comprising the gravel. Polish and friction values were determined in the laboratory with the British Wheel and Pendulum. The gravels of this study were composed primarily of carbonate aggregates that showed considerable variability in polishing thresholds. Igneous and metamorphic constituents polished to a lesser degree and are expected to improve overall aggregate performance. Estimates of the IFV (Initial Friction Value) and PV (Polished Value) for crushed gravel samples can be made based on the percentage of rock types present in the sample. A weighted average is used to make this calculation.

Key Words : Friction Resistance, Gravel Aggregates, IFV, PV,

도로에서의 미끄러짐을 방지하고 차량이 적당한 거리에서 정지할 수 있기 위해서는 적절한 마찰저항이 필요하다. 골재의 마찰저항력은 차량소통의 결과로 시간경과에 따라 마모 및 연마되어 감소하게 된다. 이 연구목적은 현장마찰 저항력을 예측하고 자갈골재간의 마찰저항치의 변화를 야기하는 원인을 규명하기 위해서 인디아나 자갈골재 실내시험방법을 개발하는 것이다. 자갈골재 연구에 대한 접근방법은 첫 번째로 각각의 구성 암석형태 및 구성비율을 분석하는 것이다. 본 연구에 사용된 자갈들은 주로 탄산염암 골재로 구성되어 있으며 연마에 의한 저항치의 변화가 심하였다. 자갈을 구성하는 화성암 및 변성암은 이에 비해 연마에 의한 저항치의 변화가 적었으며 전체 골재의 마찰저항력을 증진시키는 것으로 사료된다. 파쇄자갈시

료의 초기마찰 저항치 (IFV)와 연마 후 수치 (PV)의 평가는 시료 내 암종의 백분율에 따라 실행되었으며 가중평균이 적용되었다.

주요어 : 마찰저항, 자갈골재, 초기마찰 저항치, 연마 후 수치

INTRODUCTION

Natural aggregates used in highway construction in Indiana, USA are crushed carbonate rocks and glacial river gravels. This includes both base courses and aggregates for the pavement itself. Historically, dolomites have been specified for use in surface courses for medium volume roads and a combination of dolomite and blast furnace slag used for surface courses of high volume roads. Good friction resistance of the surface course is needed to prevent pavement slipperiness and to allow vehicles to stop in a reasonable distance. Following pavement construction, the frictional resistance of pavements has been monitored after certain time intervals using the ASTM E-274 procedure, Towed Friction Trailer. This specification method has ensured that the aggregates and the pavements are evaluated over time but the procedure has had complications. The testing time involved (5 years) has restricted the approval of those aggregate sources for which the Indiana Department of Transportation has no performance data. This includes such aggregates as granite, gneiss, and sandstone. Furthermore, identification of good aggregates for use in surface courses is a subject of increased interest as stone mastic asphalt surfaces (SMA) are now proposed for use in Indiana. Because the performance of SMA surfaces depends on a strong aggregate framework, high quality aggregates are required. The aggregates must provide adequate friction as well as high strength and durability.

Strength and durability can be predicted using physical tests, such as magnesium content, Los Angeles abrasion, sodium sulfate soundness, absorption and specific gravity, currently used by the Indiana Department of Transportation. However, a laboratory program should be developed in order to adequately predict the field frictional performance of aggregate sources. Although road surfaces would still require monitoring, initiation of a laboratory program would assist in the segregation between good and poor aggregates before their emplacement in SMA surfaces. This would ultimately lead to less maintenance requirements as a result of aggregates in these surfaces maintaining frictional property expectations. Highway friction levels are important with respect to maintaining safe driving conditions primarily during wet conditions.

OBJECTIVES

The objective of petrographic examination for the gravel samples was to describe and classify the constituents of the samples and determine the relative amounts of the constituents.

Another Objective investigated are to determine the wear and polishing properties of gravel aggregates, and how their properties affect friction resistance of pavements containing these aggregates. This study includes a detailed evaluation of standard laboratory tests to predict their field frictional performance or at least rank their performance relative to an acceptable reference range. This portion of the work focused on the British Pendulum tester and the British Wheel machine which were used to test coupons made from the gravel constituents.

EVALUATION PROCEDURES

Nature of Indiana Gravel Deposits

The major gravel resources in Indiana are found in the landforms deposited directly from glaciers or by glacial meltwater streams during continental glaciation. At first glance, the composition of the Indiana gravels seems to be a bewildering array of rock and mineral types, and in many samples 10 to 20 varieties of rocks can be found (Carr and Webb, 1970). Included are carbonates, sandstone, siltstone, chert, shale, iron clay, gneiss, schist, quartzite, granite, granodiorite, diorite, gabbro, andesite, basalt, gabbro, syenite, dacite, rhyolite, amphibolite, and quartz (Shakoor and West, 1979, McGregor, 1960). But, gravels of Indiana contain as much as 96 percent sedimentary rocks from the shale, limestone, and dolomite formations which comprise the Indiana bedrock. It has been concluded that the quartz- and feldspar-rich igneous and metamorphic rocks have been transported from northeastern Canada (McGregor, 1960). Fig. 1 shows the dominant lithologies of the bedrock in Indiana.

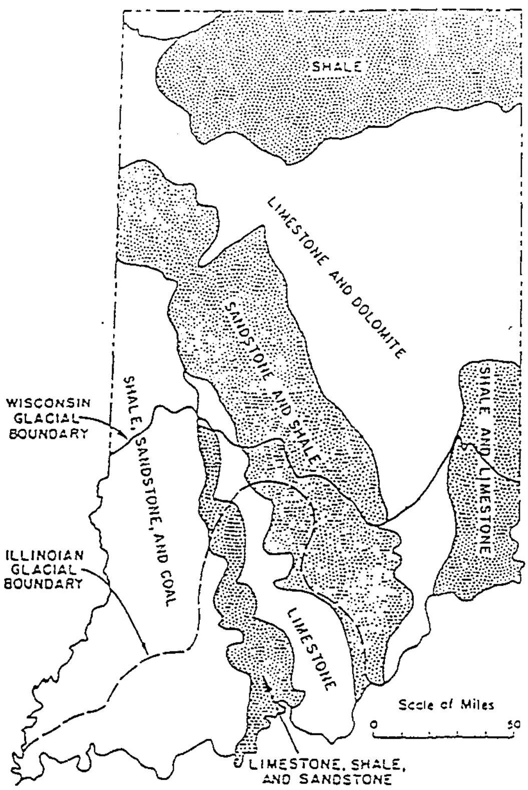

Fig. 1. Map of Indiana showing dominant lithologies of bedrock (from McGregor, 1960).

Selection of Samples for Examination

Approximately 2.5kg of a gravel sample was prepared for sieve analysis by reducing the sample material to the required quantity according to ASTM Standard C702. Then, 300 representative particles were evaluated from each of the following sieve fractions :

- 25.4mm to 19.1mm
- 19.1mm to 12.7mm
- 12.7mm to 9.52mm
- 9.52mm to No. 4

Fractions smaller than No. 4 were not included in the study because it is generally accepted that the coarse aggregate portion largely determines the skid resistance for bituminous pavements, and the finer portion represents only ten to thirty percent of the total sample used for bituminous surface aggregate. All particles in the size fraction were examined if fewer than 300 particles were present. When the sample contained less than 30 particles in a size fraction, that material was combined with the next smaller fraction before selecting particles for examination.

The percentage of crushed particles was determined according to the definition of a fractured face in the Indiana Standard Method (ISM) 204 which reads as follows :

Fractured Face--A broken surface constituting an area of at least 25% of the largest cross sectional area of the particle. A fractured particle is defined as one being fractured either by mechanical means or by nature. Natural fractures must be similar to those fractures produced by a crusher.

This examination procedure was performed three times for each gravel sample in order to obtain reliable results.

Examination of Gravels

Rock particles were identified in a surface wet condition which enhances the color and structure of the particles. Hand lens and binocular microscope were used to identify individual rock constituents. A knife was used to differentiate the common, harder minerals (quartz and feldspars) from common, soft minerals (calcite and dolomite). Then, 0.1 N HCl was applied on soft rocks to differentiate the carbonates. Limestones produced a brisk effervescence while dolomite showed slow effervescence or produced efferves-cence only when scratched. Fifteen rock types were chosen according to their frequency in the sample. If particles of indeterminate type were encountered in the samples, they were included with the known types with similar texture and hardness. Fifteen rock categories were used including : limestone, dolomite, sandstone, siltstone, shale, chert, iron clay, granite, diorite, felsite, basalt, gabbro, gneiss, quartzite and quartz, and schist.

Next, they were placed in trays labeled according to their lithologic types. When the examination of each sample was completed, the different lithologic types in each sieve size were counted, weighted and the percentages calculated.

Petrographic Examination for Gravel Samples

The objective of petrographic examination for the gravel samples was to describe and classify the constituents of the sample and determine the relative amounts of the constituents.

Information from the data sheet permits the computation of weight percentages to show :

- Percentage of gravel retained on each sieve size in the original gravel samples.
- Weight and count of selected particles on each sieve.
- Composition of fractions of the petrographic analysis on the basis of 100 percent retained on the No. 4 sieve.
- Count and weight of each lithologic type retained on each sieve size, and percentages based on count and weight.
- Percentage of carbonate, and other sedimentary rocks, igneous, and metamorphic rocks in the analyzed gravel samples based on count and weight.
- Weight percentage of carbonate, and other sedimentary rocks, igneous, and metamorphic rock in the total sample recalculated on the basis of 100 percent retained on the No. 4 sieve.
- Percentage of uncrushed gravel retained on each sieve.
- Weight percentage of uncrushed gravel in the total sample recalculated on the basis of 100 percent retained on the No. 4 sieve.

Results show that gravel samples examined consist mainly of carbonate rocks ranging from 47.8 to 84.7 percent. Igneous rock is the second

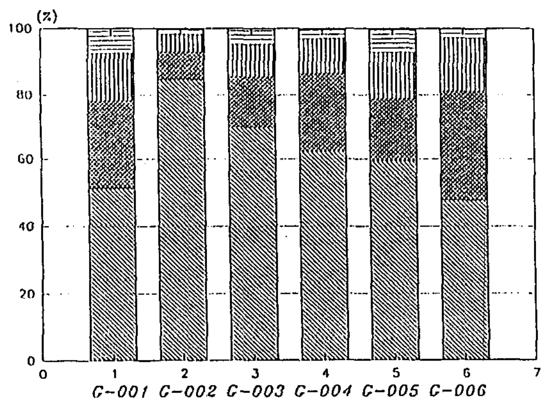

Fig. 2. Rock type distribution of examined gravel samples.

most abundant constituent of the gravel, ranging from 8.3 to 33.3 percent, followed next by metamorphic rocks ranging from 5.3 to 16.1 percent. Other sedimentary rocks such as chert, sandstone, siltstone, shale, clay ironstone, which are believed to be as deleterious materials, consist of a portion ranging between 1.5 and 7.6 percent of gravel samples. Fig. 2 shows the composition of the gravel samples examined.

British Wheel Procedure

The British Wheel test procedure involves the use of two separate pieces of equipment. The first of these is known as the British Wheel machine. The second is the British Pendulum. In the late 1950s, the Road Research Laboratory (RRL), of London, England, developed a laboratory test for investigating the extent to which aggregates used in pavement surfaces will wear and polish when subjected to heavy traffic conditions. This test was adopted as a British Standard (BS 812) for use in preevaluation of aggregate performance. Later, this procedure was included in ASTM Standard as ASTM D 3319 and ASTM E 303.

The British Wheel machine is depicted in Fig. 3. The apparatus was designed to obtain a rapid rate of wear and polish by passing each specimen of aggregate under a pneumatic tire driven at a speed of 320±5 rpm (24km/hr). The major components of the British Wheel are as follows :

- Road Wheel--Aggregate specimens were prepared and mounted on the 40.64 cm diameter steel wheel having a flat periphery 6.35 cm wide.
- Rubber Tired Wheel--Originally, an industrial 8×2 pneumatic smooth-tread hand-truck tire (Dunlop RLI 8×2) was used for this test, but Dunlop discontinued manufacturing this tire in February 1979. Therefore, an alternative tire was used for this study and modification of the steel wheel was necessary to mount the alternative tire, as per ASTM Standard D-3319. The aggregate surface was in contact with a cross-hatch pattern tread tire equivalent to a Goodyear Industrial All Weather Hand Truck Tire, size 20.22 cm diameter (Goodyear Product Code 202-008- 002) with an inner tube (Goodyear Product Code 199-010-700). The pneumatic tire was inflated to a pressure of 2.43×103 kPa. The tire rests on the road wheel test specimens with a force of 400kg. This force is developed by a weighted lever system in which the axle of the rubber tired wheel is fixed.

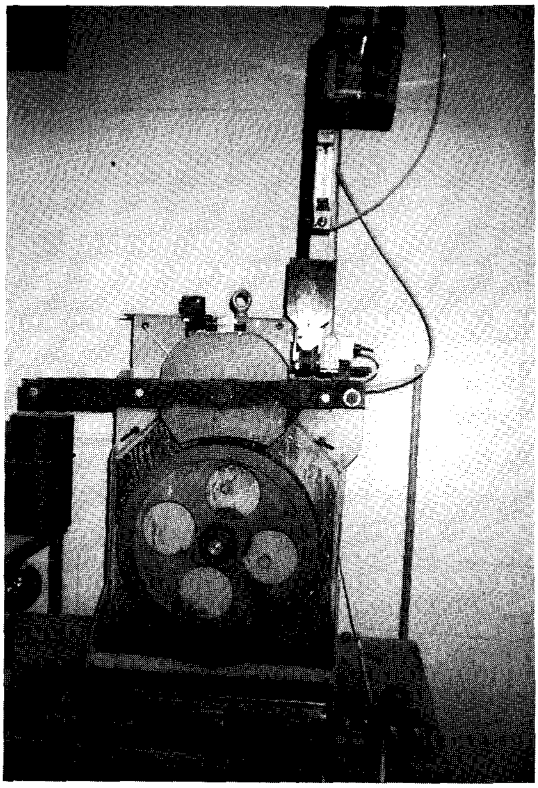

Fig. 3. The British Wheel machine.

- Grit Feed System--Accelerated wearing and polishing is induced by the continuous, uniform application of an abrasive between the rubber tire and the road wheel. 150-grit size silicon carbide grit is vibrated from a small hopper to a chute at a rate of 62g/min. Water is supplied at a rate of 50 to 75 ml/min and washes the grit onto the road wheel near the point of contact of the wheel and rubber tire.

• Aggregate Specimen--The aggregates were sieved to produce samples that would pass the 12.7mm square mesh size but would be retained on the 9.52mm sieve. They were then washed, dried, and stored for future specimen preparation. Only aggregate particles which had relatively flat surfaces and a minimum 9.52mm thickness were used for making the specimens. Each specimen was prepared by closely placing each aggregate in an inverted mold. Wax was placed on the mold sides and the top plate to act as a release agent. Ottawa sand was used to fill the space between each aggregate particle so that the tops of the aggregates were exposed. A polyester resin material was mixed with methyl ethyl ketone peroxide (MEKP) and placed in each mold to anchor the aggregate and complete the specimen. Each molded specimen was then allowed to cure for at least 3 hours before removal from the mold. The mold and the top plate were then taken apart and the molded specimen removed. The sand, placed in the bottom of the inverted mold, prevented the polyester resin from penetrating to the bottom of the mold or to the wearing surface of the specimen. Specimen preparation was a very tedious and time consuming process, and there were problems on the change of pot life whenever a new supply of polyester resin was delivered from the manufacturing company. Some prepared specimens are shown in Fig. 4.

The British Wheel simulates the polishing action of vehicular traffic on the aggregate. Fourteen curved coupons, two samples consisting of ten molds and four control specimens, are inserted along the circumference of the steel wheel. The small pneumatic tire is placed in contact with the molds on the steel wheel. As

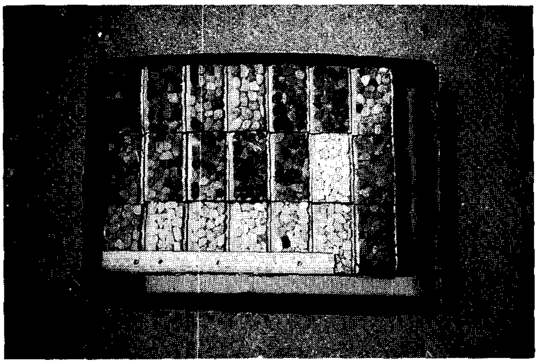

Fig. 4. Some prepared specimens.

the tire and wheel turn grit and water are evenly applied to initiate a polishing action. The aggregates are polished for a period of approximately ten hours--the period of time at which polish equilibrium generally occurs for most rock types. These results provide the polish susceptibility for a given source of aggregate. This process was accomplished using ASTM procedure D 3319, Accelerated Polishing of Aggregates Using the British Wheel.

Friction values on the aggregate coupons were measured before and after polishing using a device known as the British Pendulum. The British Pendulum Tester is a dynamic pendulum impact tester which measures the energy loss when a rubber slider edge is propelled by gravity over the aggregate test specimen (Fig. 5). After removal from the polishing wheel, each test specimen is cleaned of all grit, then locked into the specimen base. The pendulum tester is leveled and zeroed, and the height of the pendulum is adjusted so that the slider impacts the same area of the test specimen at each test, and a thin film of water is applied to the specimen. Then, the pendulum is released. A pendulum arm of fixed radius (50.8cm) and weight (2.3 kd) falls freely under gravity. The rubber slider affixed to the end of the arm makes contact with the surface under a preset normal load and for a specific contact length.

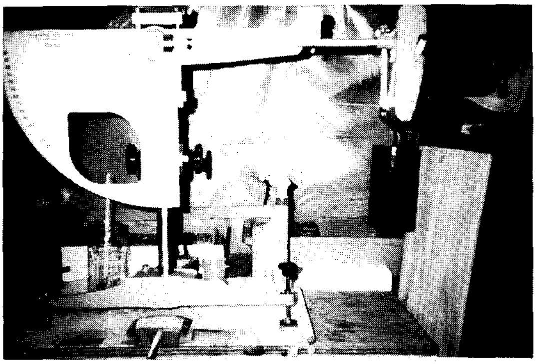

Fig. 5. The British Pendulum tester.

The angle between the pendulum arm and the horizontal after the slider passes over the surface is a measure of the energy absorbed by that surface. A large angle indicates a high energy loss, whereas a small angle indicates little energy loss. When the pendulum arm is released from a fixed initial horizontal position, it carries a pointer along a circular scale calibrated to read frictional measurements known as British Pendulum Numbers (BPN). The numbers range from 0 to 150.

The values obtained from the first three swings are not recorded, so as to allow the slider to self-adjust to the surface of the specimen. Five swings are then made, and their values recorded along with the numbers of hours of polishing. Water is added between each recorded measurement. Prior to polishing an aggregate sample the friction value of the aggregate is determined with the British Pendulum and termed the Initial Friction Value (IFV). The BPN obtained as a consequence of polishing with the British Wheel and measured with the British Pendulum is called the Polished Value (PV). The difference between the IFV and PV is termed the Wear Index (WI), which indicates a reduction in frictional resistance depicted for a given aggregate source.

RESULTS AND DISCUSSION

Reliability of Data

Two frictional values were ultimately obtained on each aggregate specimen using the British Wheel apparatus. The first value is obtained for the specimen before it is tested on the British Wheel and is known as the Initial Friction Value (IFV). The second value, so called Polished Value (PV), is recorded after the aggregate specimen has been polished for ten hours, unless the polish value is achieved in a short time according to ASTM Standard D-3319. The ASTM specified 10 hours of polishing is equivalent to about 200,000 revolutions. The difference between the Initial Friction Value and the Polished Value is termed the Wear Index (WI) and is a relative measure of the amount of aggregate polishing that occurs.

For the 14 specimens, two sets of five specimens of a different aggregate source were tested with four specimens of the same reference aggregate (control specimen). The reference aggregate (standard aggregate) was used to determine the precision of the British Wheel test. The reference stone is from an aggregate source of reef dolomite. For this study, a sufficient quantity of reference stone was obtained on one quarry visit to complete the research.

A British Pendulum Number was determined initially and then after 1, 3, 6, and 10 hours to obtain a plot of BPN versus time. This shows the shape of a non-linear exponential decay function (Fager and Smith, 1990). Some selected aggregate sources were tested for an additional time, 14, 18, and 20 hours to evaluate the polishing effect and variation of BPN.

According to historical perspectives, the tentative acceptance criteria for the minimum polish value permitted for surface course mixes is shown in Table 1. These limits are only a starting point for future refinement. Fig. 6 shows

Table 1. The tentative acceptance criteria for the minimum Polish Value (PV).

Minimum Polish Value	Quality
24 or less	Poor
25 to 30	Marginal
31 or more	Good

a relationship of BPN vs. time for selected aggregate 20 hours. All have declined from IFV and show declining values or a leveling off at 10 hours. Note that polishing for 10 hours seems to be sufficient and practical to establish a consistent polished value (PV).

First, nine specimens of the reference sample (D-001) were polished and tested. The BPN values of the reference sample were compared with those of four control specimens (D-001) whenever new sets of aggregate sources were tested. There were 27 sets of BPN data completed on the control specimen (also referred to as the standard aggregate). Correlation between a standard aggregate and a reference aggregate indicates that an average range of standard deviation for the standard aggregates is 1.8 BPN units, and the mean value of the standard aggregate and the value of the reference aggregate show that there is not much difference between those values.

For the recorded data of five swings for each specimen at each time interval, only the last four data sets were used for statistical analysis. The standard deviation for each specimen was less than 1.0 BPN unit. According to ASTM Standard

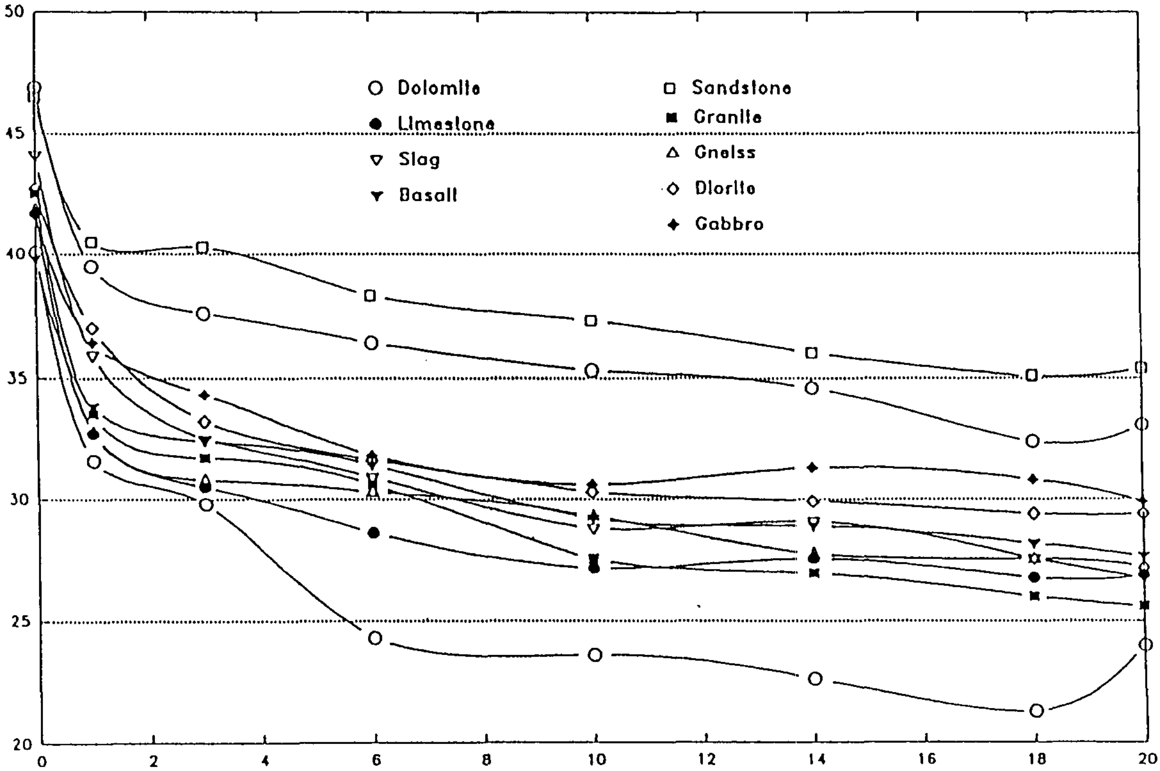

Fig. 6. Results of the British Wheel test for selected sources (20 hours).

E-303, the standard deviation is a maximum of 1.0 BPN unit for the British rubber slider.

The gravel sources tested using the polishing test were subdivided according to rock types, in order to evaluate the characteristics of these individual rock types. Some rock types such as quartzite, sandstone, and chert were not tested because those pieces were either elongated and/or did not constitute enough pieces to make a proper coupon specimen. Some problems occurred in the testing of coupons made from uncrushed gravel specimens. Occasionally aggregate particles popped out from specimens. If enough particles were lost, the specimen would break apart and fall from the wheel. Broken specimen were replaced by previously used standard specimens and the testing process continued.

Dolomite in gravel sources

Dolomite in the gravel shows a considerable variation in BPN depending on the source (See Fig. 7 and 8).

It seems that dolomite characteristics are related to the local bedrock or where a gravel pit is located geographically. 100% crushed dolomite shows the highest values, 50% crushed dolomite shows intermediate values, and uncrushed dolomite show the lowest values. Observations made with the PV indicate that 100% crushed dolomite still showed the highest values, but

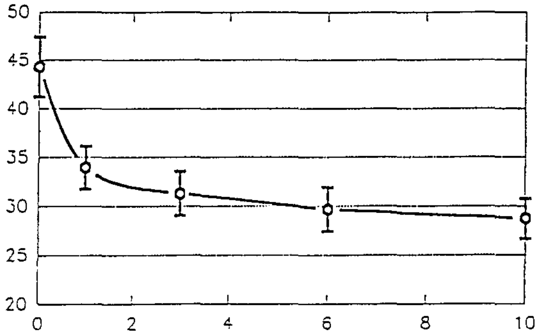

Fig. 8. Error bars for dolomite in gravel sources.

there was no relationship between 50% crushed and uncrushed dolomites. However, uncrushed dolomite show the lowest values for WI. In other word, uncrushed dolomites show the highest resistance to polishing.

Limestone in Gravel Sources

Limestone in the gravel sources also shows that BPN varied considerably depending on the source (Fig. 9 and 10). 100% crushed limestone shows higher values than that of uncrushed limestone. In the case of PV value, 100% crushed limestone still shows higher values than that of uncrushed limestone. But, regarding WI, 100% crushed limestone shows higher values than that of uncrushed limestone. Limestone in the gravel sample had a lower initial average IFV and was polished to an even lower average PV as

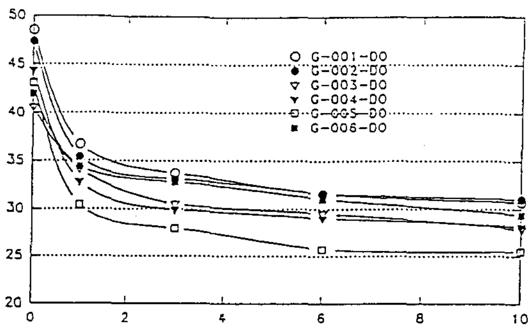

Fig. 7. British Wheel test results of dolomite in gravel sources.

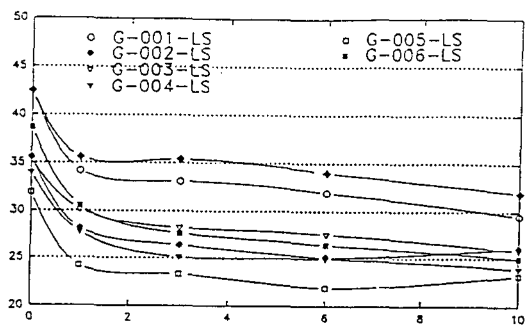

Fig. 9. British Wheel test results of limestone in gravel sources.

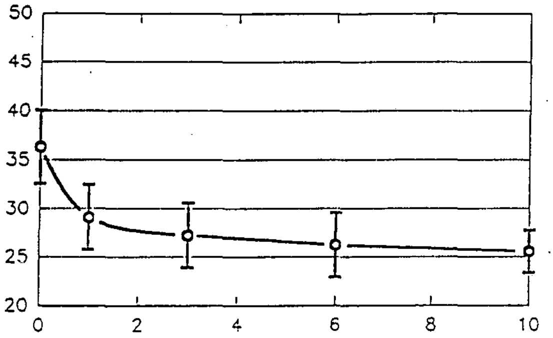

Fig. 10. Error bars for limestone in gravel sources.

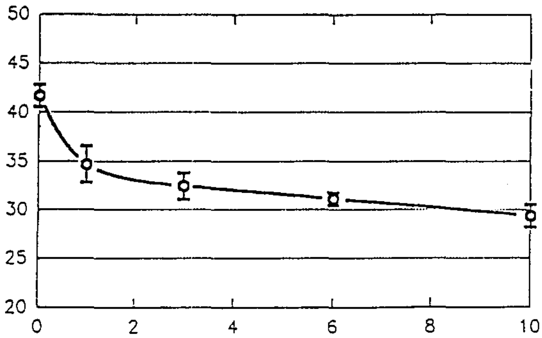

Fig. 12. Error bars for igneous and metamorphic rocks in gravel sources.

compared to dolomites in the gravel.

Igneous and Metamorphic Rock

Basalt, gabbro, granite, diorite, and gneiss were selected to perform friction resistance testing. Individual specimens of one rock type were prepared from a single gravel source. These rocks show similar values for both IFV and PV (see Fig. 11 and 12). In the Michigan Department of Transportation specification on aggregate (MTM 111), igneous and metamorphic rocks are regarded as one rock type.

Average Initial Friction Values (IFV) for igneous and metamorphic rocks are lower than those for dolomites in gravel, but the average of Polish Value (PV) is higher. Therefore, igneous and metamorphic rocks in the gravel sources are

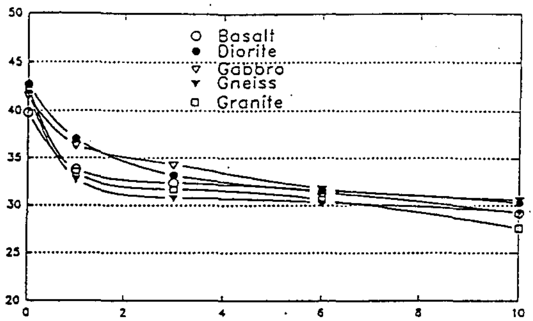

Fig. 11. British Wheel test results of igneous and metamorphic rocks in gravel sources.

expected to improve frictional resistance for these gravel aggregates, which in Indiana are composed mainly of carbonate rocks.

An estimate of the IFV and PV for crushed gravel samples can be obtained by using information from the previous discussion (See Table 2). It is summarized below :

First a megascopic petrographic exam is performed. In this procedure the percent of rock constituent is obtained for a crushed gravel as follows : dolomite, limestone, igneous and metamorphic and other sedimentary rocks. A weighted average is used to estimate the IFV and PV for the gravel samples.

Table 2. The estimate of IFV and PV for crushed gravel samples.

I. D.	IFV	PV	Remarks
Dolomite	44.3	28.8	100% crushed
Limestone	36.4	25.8	〃
Igneous and Metamorphic rocks	41.7	29.4	〃

CONCLUSION

The research results for this portion of Project

HPR-2082, Development of a Procedure to Identify Aggregates for Bituminous Surfaces in Indiana, proved to be quite successful. This development alone permits the ranking of potential surface course aggregates on the basis of their resistance to polishing.

The gravels of this study were composed primarily of carbonate aggregates that showed considerable variability in polishing thresholds. Igneous and metamorphic constituents polished to a lesser degree and are expected to improve overall aggregate performance.

Crushed gravels generally showed Polished Values of approximately 28. If a minimum acceptable value is designated for either the Initial Friction Value or Polished Value, an acceptance criteria could be established.

Estimates of Initial Friction Values and Polished Value for crushed gravel samples can be made based on the percentage of rock types present in the sample, and the average values obtained in the coupon samples using the British Wheel test method.

The physical tests give an indication of aggregate durability and soundness. This indicates that INDOT should continue to analyze their aggregates for physical parameters such as sodium sulfate soundness loss, Los Angeles abrasion, absorption and specific gravity. Although the British Wheel and Pendulum tests are currently a necessary step in expanding the data base, eventually it likely can be omitted when enough data becomes available to allow the prediction of most untested sources.

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